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International Council for the
Exploration of the Sea

https://doi.org/10.17895/ices.pub.9565

C.M.1970/F:14
Demersal Fish (Northern) Committee

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REPORT OF THE NORTH SEA FLATFISH WORKING GROUP

Copenhagen, 15-19 June 1970

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REPORT OF THE NORTH SEA FLATFISH WORKING GROUP

1. INTRODUCTION

Following a request made at the 1969 Council Meeting in Dublin, the Working Group on Assessment of Demersal Species in the North Sea was divided into a North Sea Roundfish Working Group and a North Sea Flatfish Working Group.

1.1 Participants

The North Sea Flatfish Working Group met in Copenhagen from 15 June to 19 June 1970 with the following members participating:-

J. F. de Veen	Netherlands (Convenor)
R. De Clerck	Belgium
M. J. Holden	United Kingdom
H. Knudsen	Denmark
F. Lamp	German Federal Republic
J. Møller Christensen	Secretary, Liaison Committee.

1.2 Terms of Reference

The principal tasks of the Working Group were to assess further the state of the sole stock in the North Sea following a rapid increase in the last years in the total fishing effort, and to consider the situation in the plaice fisheries with a view to the effect of discarding fish at sea. The Working Group agreed to consider the sole fisheries first, and to postpone an assessment of the plaice fisheries for another meeting. It was also agreed to treat the sole fisheries as a unit stock.

1.3 Reference to Previous Working Groups

The situation in the sole stocks has been assessed before. The Liaison Committee Report 1963 and the Report of the Working Group on Assessment of Demersal Species in the North Sea 1969 give results of assessments of the sole fisheries in prior periods.

1.4 Definition of Objectives

The objectives of the present Working Group were the following:-

a) to bring information on total landings and effort up to date;

b) to assess mortality rates by means of the virtual population analysis;

c) to make an assessment of the present situation in the sole stock with particular reference to the effects both of changes in fishing effort and in mesh-size. To this end the available information on the natural mortality rate and the growth parameters should be reconsidered.

2. LANDINGS

2.1 Table 1 shows the landings from 1960 to 1969. The figures are mainly derived from national statistics and represent the landed weight of gutted fish. They are, therefore, not in complete accordance with the nominal catch data given in the Report of the Working Group on Assessment of Demersal Species in the North Sea which dealt with the fluctuations of catches from 1906 to 1966.

2.2 After a decline to about 11 000 tons in 1964, which was mainly caused by the cold winter in 1963, the total catch rose to 32 000 tons in 1967 which is the highest figure ever recorded. Since then there has been a slight decrease to 27 500 tons, in 1969, but still the sole catches in the North Sea are at a higher level than previously. The former good period was from 1960 to 1963, when a maximum yield of 26 000 tons was obtained in 1962, due mainly to the influence of the very large year-class of 1958.

2.3 The recent high total catch figure is mainly due to two factors:

a) recruitment of the very strong year-class of 1963 to the fishery, and

b) the increase in the size of the Dutch fleet and the development of the Dutch beam trawl fishery.

Since 1965 the 1963 year-class has constituted a considerable proportion of the catches, 66% in 1965, 83% in 1966, 67% in 1967, 41% in 1968 and 24% in 1969. These percentages are based on the numbers of fish of the 1963 year-class in the catches; on a weight basis, this year-class constituted more than one-third of the total catch in 1969.

Between 1966 and 1969 Dutch landings increased by about 75% and in recent years they have formed nearly 80% of the total international landings, compared with 58% in the period 1960 to 1962. Over the same period landings by other countries have decreased, except for those by Belgium which have remained at about the same level.

3. EFFORT

3.1 Index of International Effort

The previous Working Group found it difficult to obtain a good index of effort in the sole fisheries. As they had to give a historical review over a long period, the effort of English trawlers was chosen because this provided the most continuous record, although the English fishery was not primarily for soles. After 1963, however, English trawlers fished mainly for plaice and cod and this, combined with changes in the size of trawlers of the fleet, made them an unreliable index of fishing effort.

When restricting the number of years under review to the post-war period, the Dutch otter trawler fleet provides another continuous record which runs to the present. The index is not ideal because the Dutch fleet originally fished mainly for plaice and did not concentrate on soles until 1952-1953; also there have been increases in the efficiency of Dutch otter trawlers. However, it was considered that this fleet provided the most reliable index of fishing effort.

Following 1962, the beam trawl was introduced in the Dutch sole fisheries, because it is more efficient, but it cannot be used as a standard, because its efficiency has constantly increased.

In the Dutch statistics no separation has been made between either landings or effort by otter trawlers and by beam trawlers. In order to get an estimate of total effort in terms of Dutch otter trawler units all fishing effort was converted using estimates of the percentage of beam trawlers in the Dutch fleet and of the relative efficiency of the beam trawl, in the following way:-

a = total hours' fishing by all Dutch trawlers;

b = percentage of hours' fishing by Dutch beam trawlers;

c = a x b = hours' fishing by Dutch beam trawlers;

d = $\frac{\text{catch rate of beam trawlers}}{\text{catch rate of otter trawlers}}$ (these ratios are given in Table 2)

e = c x d = effective hours' fishing by Dutch beam trawlers in otter trawler units;

f = a - c + e = hours' fishing in Dutch otter trawler units;

g = Dutch catch rate = $\frac{\text{Dutch landings of soles in gutted weight}}{(a - c + e)}$

Total international fishing effort in terms of Dutch otter trawler units =

$$\frac{\text{Total international catch in gutted weight}}{g}$$

3.2 Effort in the Period 1947-1969

Total international fishing effort in terms of Dutch otter trawler units is given in Table 3. The data for total international effort based on English motor trawler units are given in Table 4 and sets of these data are plotted for comparison in Figure 1.

In general, both curves show the same trend. After the end of the war total effort increased, at first slowly, but since 1958 more rapidly. The fastest increase took place after 1963, but the figures suggest that the total effort has levelled off in the last three years.

4. MORTALITY ESTIMATES

4.1 Previous Mortality Estimates

4.1.1. Total mortality rate

The Working Group on Soles which met in 1962 (ICES, 1965) estimated from an analysis of tagging data that the total mortality rate was 0.6. This value was much higher than that obtained by an analysis of age data made by Boerema, Gulland and Zijlstra (1963), who obtained values of Z ranging from 0.27 to 0.35. They suggested that shedding of tags was responsible for the discrepancy between the two estimates, but data presented by Møller Christensen (1964) agreed with the earlier estimates.

At the 1968 meeting of the Working Group on the Assessment of Demersal Species in the North Sea (ICES, 1969) a value of Z = 0.6 was used, estimated from Dutch and Danish age-composition data, using comparison of catch-per-unit effort of the same year-class in successive years.

4.1.2. Natural mortality rate

Boerema, Gulland and Zijlstra (1963), in the absence of other data from which to estimate the natural mortality rate, used a method based on the length distributions of landed fish and the small amount of fishing during the period 1939-1945. Using this method they derived a mean estimate of M = 0.08. As some fishing took place during this period, they suggested that M was likely to be lower than this, probably about 0.06 and made assessments based on values of M = 0.035, 0.070 and 0.105.

At the meeting of the Working Group on Assessment of Demersal Species in the North Sea in 1968 (ICES, 1969) no additional data on natural mortality were available and assessments were made based on M = 0.035 and M = 0.105, it being suggested that the lower value was the more probable.

4.2 Re-Assessment of Mortality Rates

4.2.1. Total mortality rate

The total mortality rate was estimated using two methods:-

(a) Comparison of catch-per-unit effort of the same year-class in successive years;

(b) The virtual population analysis.

Method (a) was used for both the Dutch and English data, the results being shown in Tables 5 and 6. As can be seen from the Tables estimates of Z obtained when using this method are very variable. There are several reasons for this:-

(i) the availability of soles varies from year to year, and is markedly affected by cold winters;

(ii) the estimates depend upon the assumptions made in assessing effort (see 3.1);

(iii) the size of year-classes varies widely and estimates of Z for small year-classes will be subject to large errors arising from sampling and mistakes in ageing older fish.

Estimates of Z were also made using the method of virtual population analysis, which is based on the total numbers of fish landed of each age group. Age-composition data were available for England from 1950, the Netherlands from 1957 and for Denmark from 1959.

The average age of soles landed by England is higher than that for other countries, so the English data for 1950-1956 could not be used directly to estimate the total landings of each age group. To estimate the landings by other countries, the English age composition was corrected for each age group by the following factor:

$$\frac{\text{Number of soles of age group (x) landed by Dutch in 1957}}{\text{Number of soles of age group (x) landed by England in 1957}}$$

(x) = age of fish

For the period 1957-1958 the Dutch age data were taken as representative of all nations other than England, and for 1959 and subsequent years the Netherlands and Danish trawl data; Danish gill-net data were incorporated separately. The total age-composition data are given in Table 7. Using these data an analysis was made using a value of M = 0.15. Initial estimates of E were obtained from estimates of Z for the oldest age groups using method (a). Results are given in Table 8.

4.2.2. The natural mortality rate (M)

Estimates of M were made from the regression of Z upon total international effort, using both the estimates of international effort in terms of Dutch otter trawler units and English motor trawler units and the estimates of Z based on the appropriate national data. (The data given in Tables 5 and 6 were not used directly but grouped as necessary; for the Dutch data mean values of Z were taken from 5/4+ up to 1963/62 and from 4/3+ from 1964/63 onwards). The Dutch data gave an estimate of M = 0.41 ± 0.18 and the English data an estimate of M = 0.36 ± 0.11. However, the slope of the regression for the English data was negative and the estimate of M is therefore unreliable. From Figure 2 it is seen that the high estimate of M obtained from the Dutch data is dependent upon the value of Z estimated from the most recent years' data and that these estimates are lower than would be expected. Elimination of these three points would result in a negative estimate of M.

As has already been stated in Section 3.1 English motor trawler units are not a reliable index of fishing effort in recent years. It is possible too that the efficiency of the Dutch beam trawl has been

underestimated which would increase the estimates of both Z and international fishing effort in Dutch otter trawler units. If this were so it would move the points opwards and to the right, aligning them with previous points. The virtual population analysis shows that Z is increasing with time (Table 8), whereas the data in Figure 2 indicate that it is decreasing with time. This suggests that the efficiency of the Dutch beam trawlers relative to otter trawlers has been underestimated, but the Working Group had insufficient time to investigate this point further. On the other hand, changes in availability (q) may have occurred in recent years; the Dutch are now also fishing hard, rocky ground, which earlier they did not, and the availability on these grounds may be lower than on those with sandy or muddy bottom.

The virtual population analysis gives an estimate of the population of each year-class at each age. For the 1949 and subsequent year-classes estimates of 3-year-old soles were available but for earlier years the youngest age group included in the calculations became progressively older. However, by assuming that the average fishing mortality rate over the first four years for which data are available (1951-1954) was similar to that in earlier years it is possible to estimate the number of 3-year-old soles in each year-class. If it is also assumed that there has been no change in the upper and lower limits of the sizes of year-classes for those years for which it is possible to make these estimates (1931-1966) then the best estimate of M is that which will give estimates of the size of the 1931-1948 year-classes as 3-year-olds within the same range as the size of the 1949-1966 year-classes.

In the virtual population analysis decreasing estimates of M result in decreasing estimates of the population at a given age so that increasing values of M have to be used to bring the estimates of 3-year-old soles for the year-classes 1931-1948 to the same order as those for the year-classes 1949-1966. For example, for the 1937 year-class the relative size of the estimated populations as 14-year-olds is 71.2 for M = 0.35, 49.2 for M = 0.30 and 34.0 for M = 0.25. As F would be the same for each of these populations over the age-range 3-14 years, then the lowest value of M required to bring the population to a given size as 3-year-olds would be that applicable to the largest population as 14-year-olds. Analyses were made for several values of M, the results of which indicated that M was of the order of 0.10 to 0.15. The estimates of population sizes as 3-year-old fish for these two values of M are given in Table 10 and they indicate that the lower value is the more probable. This value of M takes into account the effect of cold winters occurring at the frequency in the period covered by the data.

These estimates are higher than those used by previous working groups and the reasons for this were considered. Boerema, Gulland and Zijlstra's method assumes that the year-classes from 1937-1942 were of equal size. The virtual population analysis shows that those of 1941 and 1942 were much smaller than those of 1937-1940. This would reduce the numbers of small soles relative to older fish and lead to an underestimate of M by their method. Also the winters of 1940-1941 were severe and it is known that cold winters cause increased mortality amongst soles. Young soles are worst affected because they are closest inshore. The effect of this would be to reduce the relative size of the 1941 and 1942 year-classes still further and increase the underestimation of M. Also, if M is of the order which they estimated a higher proportion of old soles should be found in the landings than actually occurs (see Table 7).

The present method used in estimating M assumed that there has been little or no change in recruitment over the last 33 years. It is possible though that these values of M are underestimates and that recruitment was higher in the period 1932-1947, and has subsequently fallen as the stock size has decreased. However, the catch-rate data for the period 1932-1938 (ICES, 1969, Figure 8) show that the abundance of soles was about, or slightly below, the level for the period 1948-1955, although the comparison is not straightforward, because catches in the post-war period were light due to the reduction of fishing during the war and the effect of the large year-class of 1947. Also, if higher values of M are assumed, the estimates of the number of 3-year-olds decline rapidly as the number of years for which the back-calculation has been made decreases. As the main effects of the Dutch fishery on soles were not experienced until after 1952, no reduction in recruitment, due to fishing, should have been experienced until about 1955. It is therefore concluded that the assumption about year-class sizes is justified and that the figures in Table 10 represent good estimates of the relative size of year-classes.

5. ASSESSMENTS

5.1 Effort Assessments

5.1.1. Previous assessments

The Working Group on Assessment of Demersal Species in the North Sea (ICES, 1969) made an effort assessment and constructed yield curves on the basis of the Beverton & Holt constant parameter model. Yield per recruit and catch-per-unit effort against the fishing mortality rate were calculated using the following parameters:

M	t_o	t_r	t_c	t_{max}	K	L_∞
0.035 0.105	-0.76 yr	1.5 yr	2.5 yr	∞	0.26	39.2 cm

The growth parameters for the sexes combined were derived from Danish and Dutch data for the second quarter in the years 1960-1964.

It was found that a reduction in effort would result in a theoretical increase in the yield per recruit and the catch-per-unit effort. However, it was felt that in practice this increase would be lower than expected owing to the adverse influence of cold winters. (The estimate of M used by the previous Working Group did not include natural mortality due to cold winters.) These winters, occurring on average every 5-8 years, would partly eliminate the increase in stock abundance by increasing both natural mortality and fishing mortality.

5.1.2. Present effort assessment

The Flatfish Working Group carried out a new effort assessment, using the natural mortality rate arrived at in Section 4.2.2. and up-to-date growth-parameter values derived from Danish data for the 2nd quarter of the years 1964-1969. These data agree with the Dutch data for the corresponding period.

Yield curves on the basis of the Beverton & Holt constant parameter model were constructed for males and females separately and combined afterwards. The following parameter values were used:-

	M	t_o	t_r	t_c	t_{max}	K	L_∞
Males	0.10) 0.15)	-0.4 yr	1.5yr	2.5yr	22 yr	0.35	344.5 g
Females	0.10) 0.15)	-0.4 yr	1.5yr	2.5yr	30 yr	0.27	829.7 g

The yield per recruit and the catch-per-unit effort curves are given in Figures 3 and 4.

Reducing effort by 50 per cent from its present level of F = 0.6 will maximise yield per recruit, irrespective of the true value of M within the range 0.10 to 0.15 although actual gains in both total yield and catch rates will be greater the lower the true value of M. These conclusions agree with those of the former Working Group (ICES, 1969). Further increases in total effort will definitely lead to a decrease in the total yield as well as in the catch-per-unit effort. Moreover it is possible that a further increase in effort will eventually lead to the situation in which the stock is reduced to such a level that recruitment will be affected in a negative sense (Section 6).

5.2 Mesh Assessments

5.2.1. Previous assessments

Results of mesh assessments were published in both the Liaison Committee Report 1963 and in the Report of the Working Group on Assessment of Demersal Species in the North Sea (ICES, 1969). The

Working Group on Assessment of Demersal Species in the North Sea, using the method of Gulland (1961), found that immediate losses would be large even for small increases in mesh-size. Long-term gains could be expected, although the magnitude of these depended on the value of M assumed, being lower at M = 0.105 than at M = 0.035.

5.2.2. Present mesh assessments

The North Sea Flatfish Working Group re-assessed the effect of changes in mesh-size using the parameter values mentioned in Section 5.1.2 and constructed a curve for the yield per recruit against mesh-size on the basis of the Beverton & Holt constant parameter model. A selection factor of 3.3 was used, the same as that used by the former Working Group. At present a mesh-size of 75 mm polypropylene (= effective mesh-size of 80 mm, manila) can be assumed. The resulting yield curve is plotted in Figure 5 and demonstrates that small long-term gains can be expected up to 95 mm. This is in agreement with the results of the former Working Group for the higher of the two estimates of M which it used.

6. STOCK AND RECRUITMENT

Estimates of the size of recent year-classes (1959-62, 1964-66, Table 10) show that average recruitment has fallen compared with the period 1948-57. However, the data for earlier years (1943-44) show that fluctuations in recruitment occurred at times at which fishing could have had little effect on the size of the stock.

Fishing has now reduced the stock size, as indicated in Figure 4, to a low level and the Working Group considered that there is a serious possibility of recruitment being affected at the present level of effort and still more so if this level is increased by other countries switching to beam trawling.

The Working Group did not have sufficient time to investigate this problem further, but it recommended that it should re-convene at a suitable time in 1971, when additional data will be available, to study the stock and recruitment relationship further.

7. SUMMARY

The main conclusions reached by the Working Group are:-

a) that fishing effort has almost quadrupled over the last six years, mainly due to increases both in size and efficiency of the Dutch fleet;

b) that at this level of effort the yield per recruit is beyond the maximum;

c) that further increases in effort will reduce the total sustainable yield still further; and

d) that the adverse effects of further increases in effort could be much more severe if recruitment to the stock is being reduced.

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Møller Christensen, J.	1964	"On growth and mortality of the sole spawning off the Danish North Sea coast". C.M.1964, Near Northern Seas Cttee., Doc.No.129 (mimeo.).

Table 1. Landing of soles from the North Sea 1960 - 1969 in 1 000 tons (gutted weight).

Year	Belgium	Denmark	France	Germany	Holland	England	Total
1960	3.8	1.7	0.4	1.6	9.3	1.3	18.1
1961	3.3	2.1	0.7	1.9	13.5	1.4	22.9
1962	3.7	2.4	0.3	1.8	16.3	1.5	26.0
1963	7.2	0.3	0.2	0.6	13.6	3.0	24.9
1964	0.8	0.5	0.3	0.3	8.3	0.7	10.9
1965	1.3	0.6	0.6	0.3	13.0	0.6	16.4
1966	3.2	0.5	0.4	1.0	25.2	0.8	31.1
1967	4.0	1.5	0.4	1.0	24.2	0.9	32.0
1968	3.5	1.5	0.3	1.0	22.6	1.0	29.9
1969	2.5	0.8	0.3 x)	0.7	22.0	0.9	27.2

x) estimated.

Table 2. Ratios of the catch-rate of Dutch beam trawlers over the catch rate of Dutch otter trawlers by years.

Year	Ratio
1962	1.84
1963	1.84
1964	1.95
1965	2.22
1966	2.78
1967	3.44
1968	4.20
1969	5 x)

x) this ratio has been extrapolated from the preceding ratios.

Table 3. Total international fishing effort in terms of Dutch otter trawler units for the period 1946 - 1969.

Year	Total effort hours x 10^{-2}
1946	9 116
1947	8 444
1948	7 867
1949	6 401
1950	8 053
1951	11 697
1952	11 476
1953	12 299
1954	12 414
1955	12 456
1956	10 506
1957	10 364

Year	Total effort hours x 10^{-2}
1958	11 045
1959	12 309
1960	13 175
1961	13 175
1962	15 567
1963	18 685
1964	16 513
1965	18 753
1966	24 759
1967	45 352
1968	49 475
1969	46 689 x)

x) the total landings for 1969 were estimated by assuming the French landings to amount to 300 tons.

Table 4. Total international fishing effort in terms of English motor trawler units for the period 1947 - 1968.

Year	Total effort hours x 10^{-2}
1947	21 158
1948	29 317
1949	44 149
1950	48 508
1951	61 778
1952	65 628
1953	49 012
1954	36 489
1955	41 920
1956	43 281
1957	55 443

Year	Total effort hours x 10^{-2}
1958	56 649
1959	64 425
1960	81 737
1961	96 255
1962	90 474
1963	52 191
1964	95 958
1965	125 776
1966	208 641
1967	182 389
1968	171 033

Table 5. North Sea Sole. Dutch data. Estimates of Z from number in each age group per unit effort (♂ + ♀).

Year / Age	1958/57	1959/58	1960/59	1961/60	1962/61	1963/62	1964/63	1965/64	1966/65	1967/66	1968/67	1969/68
3/2	-1.84	-1.71	-1.20	-1.41	-0.08	-1.45	-1.47	-1.29	-0.70	-0.15	-1.13	-0.19
4/3	-0.25	-0.25	-0.19	-0.56	0.18	-0.17	0.26	0.87	0.74	0.18	0.19	0.95
5/4	0.49	0.28	0.24	0.58	0.82	0.35	0.74	0.38	0.71	-0.62	0.69	0.72
6/5	0.45	0.24	0.12	0.50	0.26	0.78	0.93	0.62	0.83	1.24	1.83	0.67
7/6	-0.50	0.81	0.03	0.77	0.63	0.62	0.86	0.51	1.63	0.94	0.43	0.32
8/7	0.37	0.38	-0.24	0.61	0.25	0.83	1.19	1.01	0.67	0.51	0.46	0.83
9/8	-0.17	0.44	0.79	0.32	0.60	0.36	0.99	0.36	1.32	1.09	1.11	0.46
10/9	0.13	0.39	-0.13	0.08	1.06	0.65	1.37	0.86	0.93	0.85	0.16	0.38
11/10	0.04	-0.04	-0.24	0.62	-0.14	0.05	0.99	0.28	0.67	0.74	0.90	0.56
12/11	1.89	0.18	0.35	0.38	0.81	1.13	1.37	0.38	0.61	0.36	-0.03	0.31
13/12	-1.36	-1.51	-0.24	-0.06	0.14	-0.52	0.23	-0.94	0.82	0.70	1.59	0.16
14/13	-0.17	1.05	-0.01	0.77	0.44	1.47	1.48	0.79	1.89	0.81	0.21	-0.73
15/14	-0.69	1.02	1.58	0.20	0.39	0.30	0.72	0.45	4.67	1.58	0.25	1.02
16/15	0.41	2.73	-1.95	-2.43	-0.42	0.20	1.82	0.19	1.40	-1.61	-0.89	0.50
17/16	-2.14	0.79	-2.12	2.76	2.05	2.74	1.47	1.16	0.37	0.24	0.92	-
18/17	-0.61	1.04	-0.38	1.02	-0.12	-	-0.54	-0.51	-1.04	2.59	2.56	-
18+/17+	0.07	0.16	0.07	0.17	0.22	0.75	0.00	0.15	2.04	0.36	0.12	-
$\bar{Z}$ 5/4+	-0.15	0.53	0.14	0.42	0.47	0.70	0.91	0.38	1.17	0.65	0.69	0.43

Table 6. North Sea Sole. English data. Estimates of Z from number of each age group per unit effort (♂+♀).

Age \ Year	1952/51	1953/52	1954/53	1955/54	1956/55	1957/56	1958/57	1959/58	1960/59	1961/60	1962/61	1963/62	1964/63	1965/64	1966/65	1967/66	1968/67
3/2	-1.74	-2.58	-	-1.05	-3.50	-3.49	-	-	-	-1.79	-	-	-	-2.27	-1.52	-1.82	-1.87
4/3	0.80	-0.45	-0.48	0.07	-1.39	0.50	-0.59	-0.48	-0.23	0.81	-0.50	-1.89	0.52	-0.84	-0.37	-0.39	-0.73
5/4	0.31	-0.59	0.22	0.57	0.38	0.80	-0.03	0.44	0.35	-0.16	0.60	-0.30	1.00	-0.38	-0.01	0.48	0.23
6/5	0.59	-0.02	0.77	0.49	0.49	0.48	-0.55	0.37	0.61	0.60	0.23	-0.67	2.11	0.11	0.35	0.62	0.21
7/6		1.56	0.06	-0.21	0.99	1.15	1.11	0.68	1.27	1.31	-0.31	-0.19	1.07	0.05	0.17	1.05	0.87
8/7	0.84		1.69	0.68	0.26	0.81	-0.12	-0.45	1.13	-0.33	-0.37	0.35	2.03	0.21	0.28	0.55	0.05
9/8		0.12		1.49	0.44	1.70	-0.25	0.22	0.84	-0.69	0.57	-0.78	0.70	-0.05	0.41	0.20	0.59
10/9			-0.21		-0.51	-0.26	-1.02	-0.08	0.23	0.52	0.17	-0.08	1.40	1.24	0.58	0.47	0.50
11/10	0.71			-0.32		1.31	0.18	0.57	1.34	1.58	0.83	-0.16	1.54	0.29	0.00	0.65	0.00
12/11		-0.47			0.41		-1.04	0.81	0.52	-0.49	-0.49	-1.83	1.19	-0.02	0.55	0.78	-0.72
13/12	1.47		0.14			0.56		1.51	0.43	0.25	0.65	-1.27	0.87	0.77	1.12	0.30	0.00
14/13	0.92	-0.37		1.09			1.08		-0.90	-0.23	0.64	-0.73	2.27	0.82	-0.13	-0.22	0.63
15/14	3.03	-1.48	-0.75		0.45			-1.38		-	0.34	-2.05	1.81	-0.08	0.25	0.27	-0.44
16/15	-0.71	2.99	2.81	1.44		0.30			-		-	0.08	3.51	-0.03	0.13	1.02	0.21
17/16	0.10	-0.51	1.53	-1.19	-0.57		0.69			-		-	1.48	-0.25	-0.78	0.77	0.96
18/17	-	-0.20	1.48	0.36	0.22	-		0.16			-		2.62	-0.48	-0.64	1.42	-0.43
19/18	0.55	1.33	-0.11	0.25	-1.15	0.39	-		-			-		-1.10	1.10	-0.30	-0.46
20/19	0.09	-0.37	0.76	1.93	-0.92	0.49	0.39	-		-						-0.55	0.83
20+/19+	1.34	0.32	0.76	0.61	0.77	0.57	0.48	0.39	-		0.15		0.43		0.77	0.45	0.50
$\bar{Z}$ 5/4+	0.77	-0.49	0.44	0.55	0.10	0.69	0.08	0.27	0.58	0.24	0.25	-0.64	1.60	0.07	0.26	0.47	0.21

Table 7. North Sea Sole. Total numbers (in thousands) of fish caught in each age group.

Year-class	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
Age																					
20+	98	14	220	11	23	16	84	101	144	73	128	9	57	19	11	8	4	130	213		
20		43	102	17	24	20	105	0	4	0	3	18	48	15	6	7	15	351	6	51	
19			120	14	68	115	42	60	12	0	28	21	4	6	30	6	3	122	17	26	39
18				27	23	138	47	20	34	4	34	7	26	11	12	11	20	557	82	23	34
17					0	139	273	24	42	34	33	17	16	29	10	32	44	307	24	139	120
16						163	204	148	11	20	16	2	34	30	147	175	148	1 459	58	116	109
15							107	9	247	71	39	0	47	47	36	17	86	1 480	497	124	273
14								203	70	44	82	20	33	48	59	90	154	1 974	419	353	345
13									187	38	219	24	20	76	44	218	95	3 558	574	916	1 869
12										231	79	0	128	27	24	74	63	3 039	535	967	846
11											157	0	120	0	171	220	118	3 612	778	1 285	1 543
10												70	241	0	121	139	59	3 805	693	1 212	2 936
9													1 026	132	308	1 476	66	5 712	664	1 432	2 690
8														394	291	362	0	8 646	1 379	1 132	3 506
7															596	1 924	0	14 089	1 755	2 145	4 568
6																1 021	176	19 953	1 168	5 638	6 757
5																	4 000	33 887	4 820	10 828	15 616
4																		49 703	3 431	19 140	23 949
3																			9 296	17 780	23 965
2																				3 134	2 181
1																					

continued...

Table 7. (continued)

Year-class	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
Age																		
20+																		
20																		
19																		
18	20																	
17	11	67																
16	33	89	92															
15	24	44	150	137														
14	220	99	166	415	138													
13	411	403	202	418	77	510												
12	636	170	345	492	291	743	215											
11	1 291	699	422	651	268	635	256	2 421										
10	1 010	600	1 318	763	386	832	475	4 316	258									
9	1 184	1 376	2 034	3 271	753	1 403	610	4 386	369	812								
8	2 373	1 671	3 111	3 684	2 142	1 681	1 376	8 203	740	1 399	215							
7	2 923	1 498	5 318	4 436	4 370	6 214	2 984	11 619	823	2 051	403	309						
6	1 948	2 926	5 873	9 080	6 399	9 862	7 698	16 133	2 466	3 108	558	480	22 593					
5	5 199	2 729	6 815	9 795	10 680	12 847	13 595	46 498	3 753	5 094	1 026	1 874	46 990	11 271				
4	7 659	4 238	10 010	11 693	12 024	19 920	25 849	57 749	8 525	5 908	1 393	583	83 385	23 465	5 261			
3	8 397	1 247	13 120	8 350	8 476	13 076	14 851	51 802	6 021	8 044	2 450	873	130 725	26 197	13 123	20 160		
2	0	355	382	189	1 208	2 087	3 920	11 524	3 954	1 433	590	202	46 765	11 788	3 858	16 556	25 332	
1													73				966	253

Table 8. North Sea Sole. Estimate of Z using virtual population analysis M = 0.15.

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Age 20+		0.25	0.25	0.30	0.30	0.31	0.26	0.28	0.28	0.16	0.16	0.16	0.16	0.35	0.33	0.32	0.17	0.38	0.77
20	0.37	0.19	0.32	0.27	0.30	0.26	0.15	0.15	0.15	0.15	0.17	0.16	0.27	0.22	0.26	0.21	0.54	0.16	0.64
19	0.19	0.26	0.39	0.67	0.18	0.20	0.16	0.15	0.15	0.17	0.15	0.19	0.42	0.22	0.16	0.24	0.18	0.31	0.86
18	0.30	0.21	0.50	0.18	0.16	0.17	0.15	0.15	0.15	0.15	0.21	0.23	0.26	0.21	0.45	0.25	0.26	0.47	0.43
17	0.15	0.38	0.30	0.16	0.17	0.15	0.15	0.16	0.15	0.27	0.20	0.38	0.25	0.27	0.17	0.57	0.76	0.26	0.33
16	0.34	0.23	0.22	0.15	0.15	0.15	0.15	0.15	0.24	0.65	0.82	0.39	0.52	0.20	0.37	0.46	0.39	0.32	1.20
15	0.19	0.15	0.23	0.15	0.15	0.15	0.15	0.26	0.23	0.19	0.25	0.39	0.45	0.32	0.60	0.27	0.22	0.80	0.42
14	0.22	0.17	0.15	0.15	0.16	0.15	0.24	0.25	0.32	0.29	0.37	0.32	0.47	0.48	0.80	0.27	0.53	0.63	0.68
13	0.19	0.15	0.15	0.16	0.15	0.26	0.21	0.43	0.22	0.42	0.32	0.63	0.99	0.72	0.47	0.43	0.44	0.33	0.64
12	0.16	0.15	0.15	0.16	0.18	0.18	0.22	0.19	0.31	0.27	0.45	0.35	0.61	0.25	0.46	0.37	0.58	0.55	0.37
11	0.15	0.15	0.15	0.15	0.30	0.31	0.21	0.29	0.28	0.41	0.40	0.65	0.43	0.40	0.36	0.39	0.37	0.33	0.63
10	0.16	0.16	0.15	0.23	0.23	0.17	0.26	0.24	0.32	0.46	0.38	0.32	0.61	0.32	0.39	0.35	0.39	0.61	1.00
9	0.18	0.24	0.31	0.66	0.17	0.28	0.22	0.30	0.34	0.34	0.41	0.55	0.61	0.45	0.38	0.36	0.46	0.69	0.62
8	0.35	0.26	0.23	0.15	0.30	0.26	0.24	0.33	0.41	0.37	0.51	0.46	0.65	0.34	0.46	0.47	0.69	0.59	1.01
7	0.32	0.45	0.15	0.32	0.26	0.28	0.32	0.37	0.29	0.52	0.39	0.67	0.59	0.56	0.44	0.49	0.52	0.81	0.82
6	0.26	0.19	0.33	0.21	0.39	0.33	0.26	0.35	0.41	0.47	0.56	0.55	0.70	0.41	0.70	0.49	0.61	0.65	0.77
5	0.67	0.36	0.33	0.45	0.43	0.36	0.29	0.35	0.38	0.55	0.46	0.65	0.60	0.59	0.49	0.61	0.99	0.75	1.35
4	0.37	0.25	0.49	0.43	0.36	0.31	0.36	0.34	0.43	0.46	0.65	0.48	0.68	0.40	0.51	0.29	0.68	0.96	0.91
3	0.35	0.36	0.34	0.32	0.19	0.34	0.25	0.29	0.29	0.33	0.35	0.37	0.38	0.52	0.31	0.59	0.58	0.91	0.59
2	0.18	0.16	0.15	0.16	0.15	0.15	0.17	0.17	0.19	0.18	0.26	0.18	0.21	0.18	0.25	0.28	0.28	0.37	0.20
Mean	0.27	0.24	0.26	0.27	0.23	0.24	0.22	0.26	0.28	0.34	0.37	0.40	0.49	0.37	0.42	0.39	0.48	0.54	0.71

Table 9. North Sea Sole. Estimate of Z using virtual population analysis M = 0.10.

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Age																			
20+		0.20	0.20	0.25	0.25	0.26	0.21	0.23	0.23	0.11	0.11	0.11	0.11	0.30	0.28	0.27	0.12	0.33	0.72
20	0.33	0.14	0.28	0.22	0.25	0.21	0.10	0.10	0.10	0.10	0.12	0.11	0.22	0.18	0.22	0.17	0.51	0.11	0.59
19	0.14	0.21	0.36	0.66	0.14	0.16	0.11	0.10	0.10	0.12	0.10	0.14	0.39	0.18	0.11	0.20	0.13	0.26	0.81
18	0.27	0.17	0.48	0.14	0.12	0.12	0.10	0.10	0.11	0.10	0.16	0.19	0.22	0.17	0.43	0.22	0.21	0.44	0.38
17	0.10	0.35	0.27	0.12	0.12	0.10	0.10	0.11	0.10	0.24	0.16	0.37	0.22	0.23	0.13	0.56	0.75	0.22	0.28
16	0.31	0.20	0.19	0.11	0.10	0.10	0.10	0.10	0.21	0.68	0.86	0.39	0.53	0.16	0.35	0.43	0.36	0.28	1.15
15	0.14	0.10	0.20	0.11	0.10	0.10	0.10	0.24	0.19	0.15	0.23	0.38	0.48	0.29	0.59	0.24	0.17	0.77	0.37
14	0.20	0.12	0.10	0.10	0.11	0.10	0.22	0.22	0.30	0.28	0.36	0.32	0.47	0.47	0.83	0.23	0.50	0.60	0.63
13	0.16	0.10	0.11	0.11	0.10	0.25	0.18	0.43	0.19	0.41	0.32	0.65	1.02	0.73	0.47	0.41	0.41	0.29	0.59
12	0.11	0.10	0.10	0.11	0.14	0.14	0.18	0.15	0.29	0.25	0.44	0.32	0.60	0.21	0.44	0.35	0.56	0.51	0.32
11	0.10	0.10	0.11	0.10	0.30	0.29	0.18	0.27	0.27	0.40	0.38	0.65	0.43	0.38	0.33	0.37	0.33	0.29	0.58
10	0.12	0.11	0.10	0.21	0.20	0.13	0.24	0.22	0.30	0.45	0.36	0.30	0.62	0.30	0.37	0.32	0.36	0.58	0.95
9	0.15	0.24	0.31	0.73	0.13	0.26	0.19	0.28	0.32	0.32	0.42	0.55	0.63	0.45	0.36	0.33	0.43	0.66	0.57
8	0.40	0.25	0.20	0.10	0.29	0.25	0.21	0.31	0.40	0.36	0.51	0.45	0.66	0.32	0.46	0.46	0.67	0.56	0.96
7	0.33	0.47	0.10	0.32	0.25	0.26	0.30	0.36	0.27	0.52	0.38	0.68	0.61	0.56	0.43	0.46	0.50	0.78	0.77
6	0.24	0.16	0.33	0.18	0.41	0.32	0.23	0.35	0.39	0.47	0.56	0.56	0.72	0.40	0.70	0.47	0.58	0.32	0.72
5	0.89	0.37	0.36	0.48	0.44	0.35	0.27	0.34	0.37	0.54	0.46	0.65	0.61	0.58	0.48	0.59	0.99	0.73	1.30
4	0.38	0.24	0.51	0.44	0.36	0.30	0.35	0.32	0.41	0.45	0.65	0.47	0.68	0.39	0.49	0.25	0.66	0.94	0.86
3	0.37	0.35	0.33	0.31	0.15	0.33	0.22	0.26	0.26	0.30	0.33	0.35	0.37	0.52	0.28	0.57	0.56	0.89	0.54
2	0.13	0.12	0.10	0.11	0.11	0.10	0.12	0.12	0.14	0.27	0.22	0.14	0.17	0.13	0.22	0.24	0.24	0.34	0.15
Mean	0.26	0.21	0.24	0.25	0.20	0.21	0.19	0.23	0.25	0.33	0.36	0.39	0.49	0.35	0.40	0.36	0.45	0.50	0.66

Table 10. Relative strengths of year-classes of North Sea Sole as 3 year-old fish, estimated from virtual population analysis.

Back-calculated estimates			Actual estimates as 3 year-old sole		
Year-class	Population size		Year-class	Population size	
	M = 0.10	M = 0.15		M = 0.10	M = 0.15
1931	136	205	1948	411	561
1932	1 436	2 217	1949	849	1 026
1933	61	93	1950	1 216	1 474
1934	113	175	1951	473	585
1935	202	288	1952	287	379
1936	504	773	1953	668	801
1937	405	632	1954	762	935
1938	542	851	1955	609	712
1939	2 696	4 430	1956	914	1 079
1940	4 694	7 786	1957	863	981
1941	343	561	1958	2 689	3 119
1942	1 684	2 913	1959	287	323
1943	95	130	1960	359	415
1944	131	167	1961	75	84
1945	288	333	1962	56	64
1946	158	216	1963	3 622	3 934
1947	3 037	3 844	1964	750	802
			1965	251	262
			1966	593	607
Range	61-4 694	93-7 786	Range	56-3 622	64-3 934

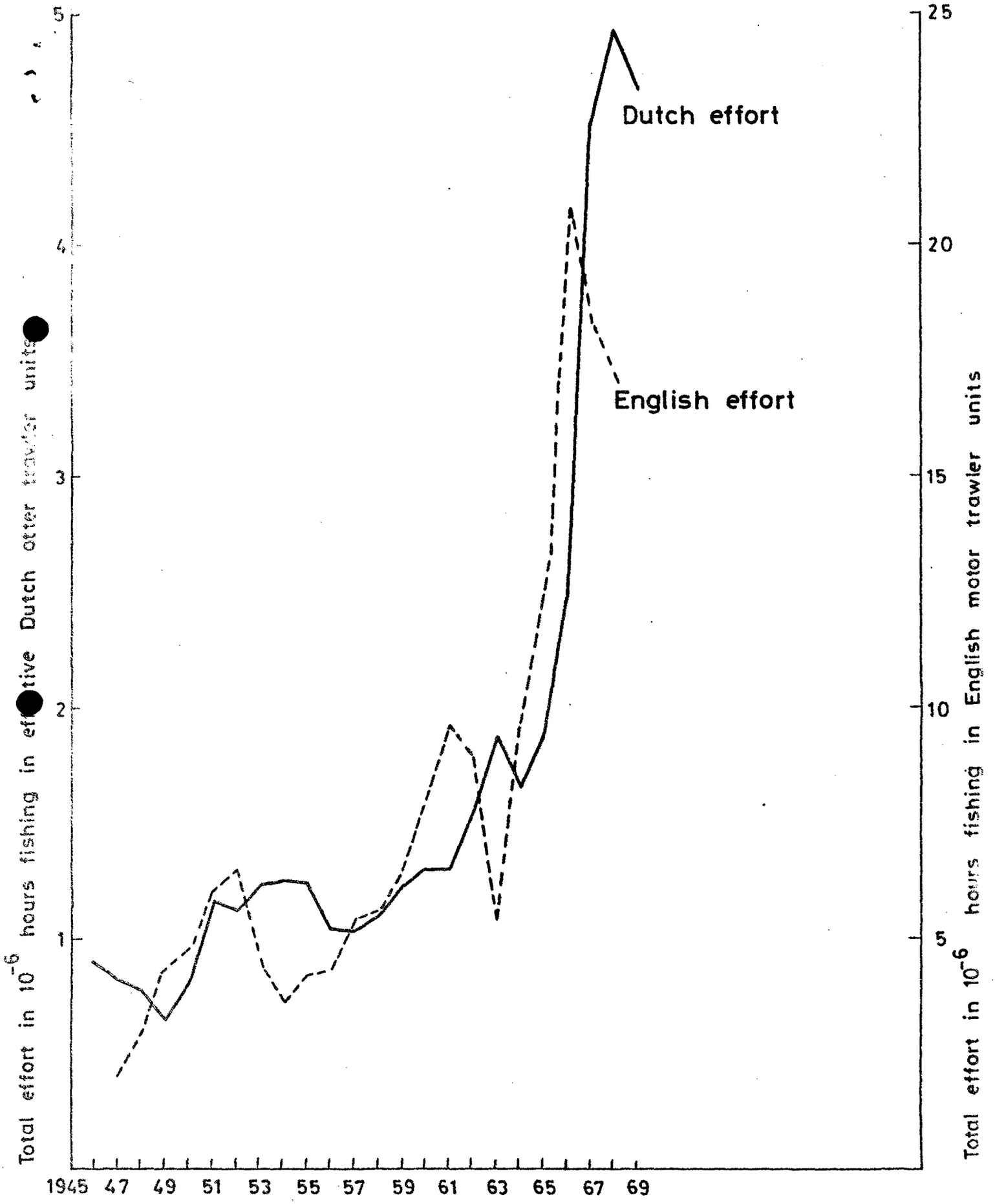

Figure 1. Total effort from 1945 - 1969.

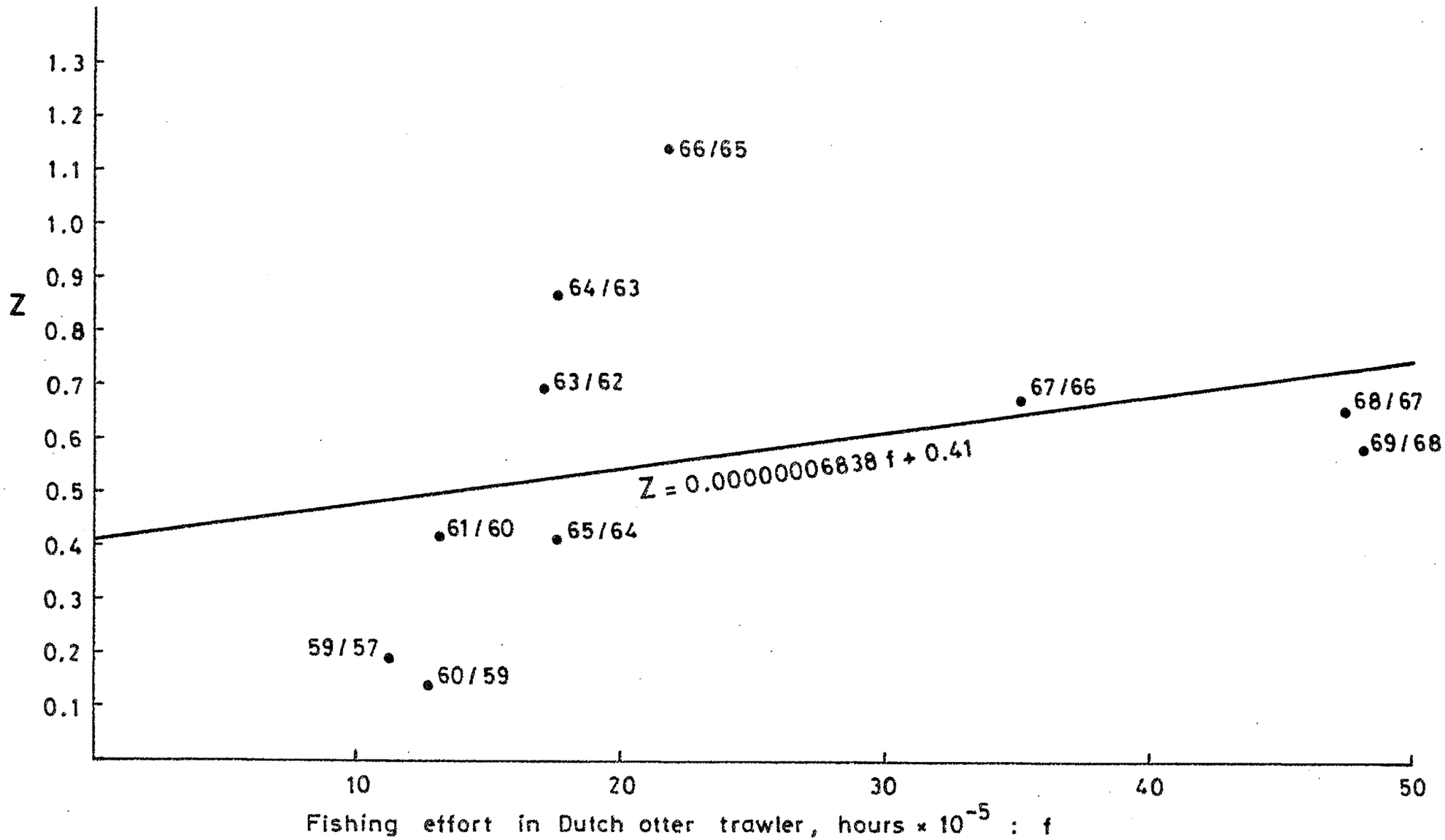

Figure 2. Regression of total mortality rate on total international effort in terms of Dutch otter trawl units.

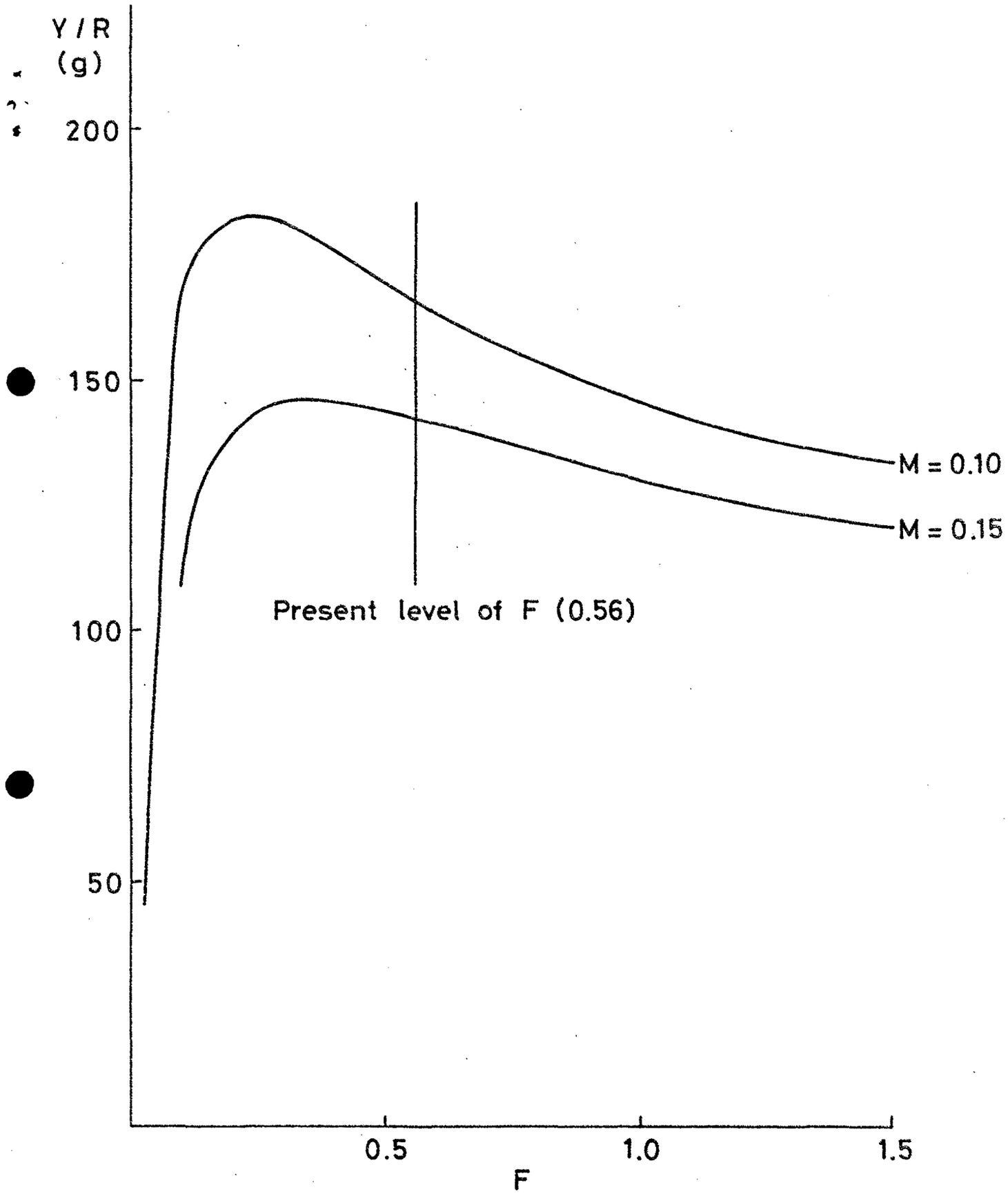

Figure 3. North Sea sole. Yield per recruit against F.

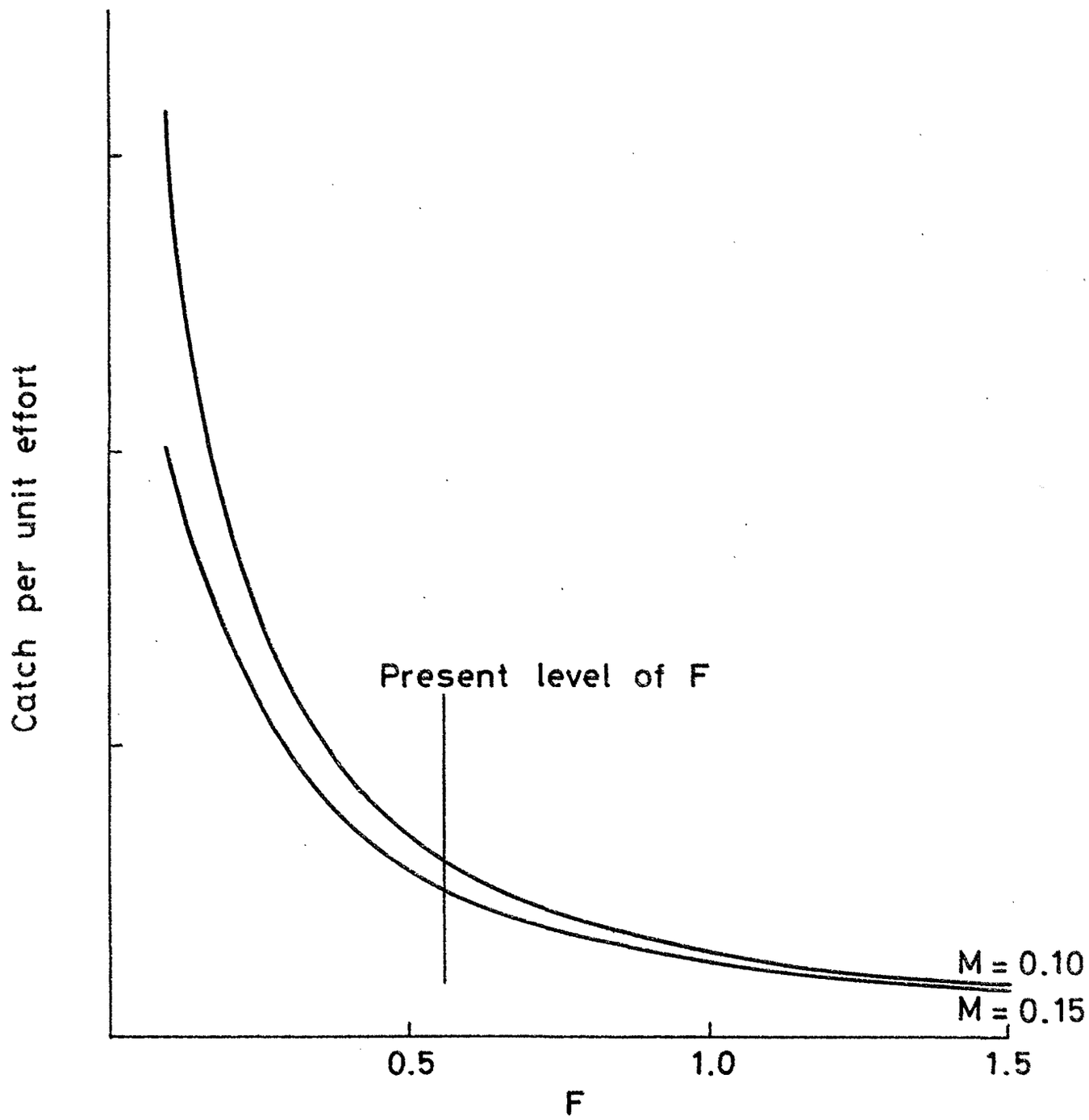

Figure 4. North Sea sole. Catch per unit effort per recruit against F.

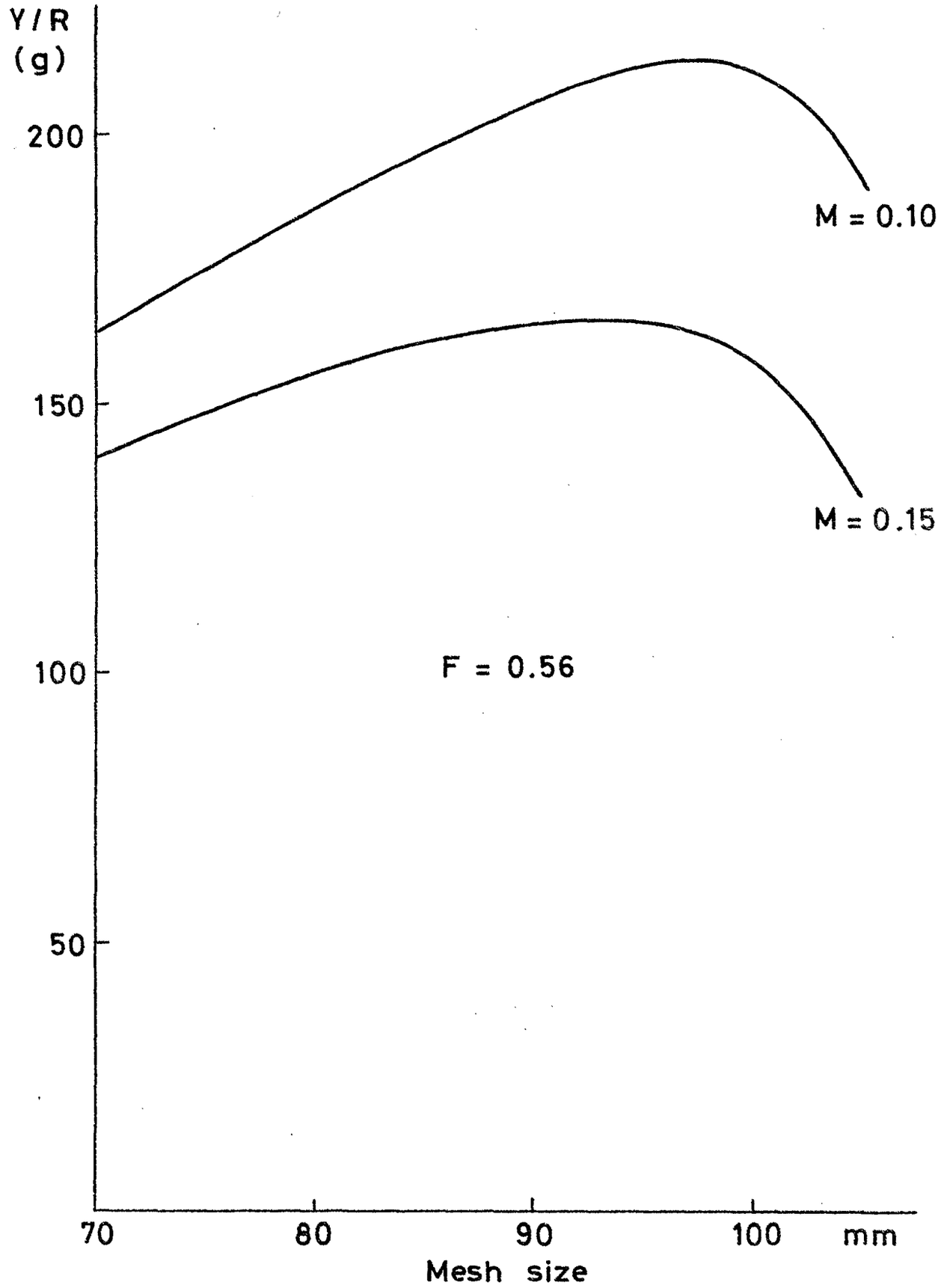

Figure 5. North Sea sole. Yield per recruit against mesh-size.